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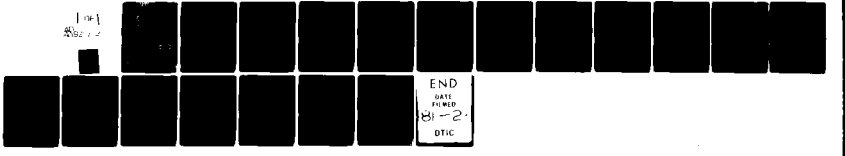

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ARMY SCIENCE BOARD

1980 SUMMER STUDY

ON

STATISTICAL TECHNIQUES IN ARMY TESTING

JULY 1980

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ARMY SCIENCE BOARD
1980 SUMMER STUDY
ON
STATISTICAL TECHNIQUES IN ARMY TESTING

I. INTRODUCTION. An Army Science Board (ASB) Summer Study was conducted at the Armed Forces Staff College in Norfolk, Virginia, 7-11 July 1980 to assess Statistical Techniques in Testing. Terms of Reference (TOR) are contained in the 16 May 1980 letter from the Assistant Secretary of the Army (Research, Development and Acquisition), attached at Appendix A. Participants in the Summer Study are listed in Appendix B. The ASB participants received preliminary briefings on 5-6 June 1980 in Washington, D.C. and, prior to the Summer Study, reviewed test plans and test results that were selected by the contributing members as examples of both good and poor testing efforts.

In order to respond to the questions in the TOR, the Study Group examined the statistical expertise available to the Army's testing communities. The Study Group concluded that this is an important factor in determining the state-of-the-art of statistical techniques in testing and a pre-requisite to assessing the TOR. Therefore, this report first discusses the expertise in the Army communities. Next, responses are given to the questions in the TOR. Finally, some conclusions and recommendations are offered for improving the quality of testing and evaluation in the Army.

II. STATISTICAL EXPERTISE IN THE ARMY. The Study Group examined the Army's statistical expertise from three aspects: the number, distribution, and quality control (management and peer review).

The distribution of statistical personnel among the Army testing agencies is shown in Table 1. The number of personnel in allied disciplines includes scientists with training in mathematics, engineering, and operations research who are involved at least part-time in statistical work. As can be seen, the commands involved in Operational Test and Evaluation (OT&E) and Development Test and Evaluation (DT&E) have about 80 percent of all the Army testing statisticians. The number of scientists in allied disciplines working in statistical areas is more than five times as great as the number of pure statisticians. The Study participants felt that both the numbers and the distribution of statistically trained personnel are adequate, with the exception that some Product Assurance Directorates (PADs), proving grounds, and Boards have no assigned statisticians. At these levels, however, contractor support is reportedly available to provide some statistical expertise.

TABLE 1

ARMY T&E STATISTICAL PERSONNEL

	Statisticians	Allied Disciplines	Total Stat. Personnel
OT&E	15	126	141
DT&E	50	233	283
PADs	16	98	114
Total	81	457	538

The Study Group was not able to review the qualifications of individual Army Statisticians. However, an attempt was made to examine the standing of the statistical community as a whole by looking for examples of outside recognition, e.g., fellowships in professional societies, awards, and publications in referred professional journals. It is the judgment of the Study Group overall quality of the statisticians is adequate, and in some cases, excellent.

In the areas of education and the dissemination of information, the Study Group found that the Army sponsors a wide variety of activities. Courses of instruction are offered through universities, the Army Management Engineering Training Activity (AMETA), and the Army Logistics Management Center (ALMC). In the last three years, the Army Research Office (ARO) has sponsored six workshops in mathematical statistics. The Army Materiel Systems Analysis Agency (AMSAA) and AMETA sponsor training workshops in reliability, methodology and reliability growth. Each year, an Army-wide conference is conducted on experimental design. Intern and cooperative student programs are conducted at the laboratories. But even with this wide variety of excellent activities, several shortcomings in statistical training were cited to the Group. In almost all these cases, a shortage of travel funds or a large workload prevented personnel from taking part in the appropriate activities.

The final aspect of expertise examined was that of quality control. It was found that quality control in terms of management and of peer review appears to be adequate in general and, at some of the major centers of statistical expertise, is very good. As will be discussed in a later section of the report, there are some levels at which quality control may not be good enough.

III. TERMS OF REFERENCE AND FINDINGS. Our findings relative to each of the specific questions in the TOR are as follows:

Question 1. What areas of Army testing lead to stated, quantified results (e.g., reliability, safety, maintainability, production acceptability/yield) with specified confidence levels?

Finding. The Study Group examined the following testing areas, all of which produced quantitative reliability, maintainability, and/or performance results:

- o Research and development
- o Development
- o Operational
- o Acceptance
- o Surveillance

Question 2. What experimental models are currently applied to such confidence-level-related testing? How could more modern test designs and models maintain the same confidence levels while reducing test expenses?

Findings. In its examination of testing, the Study Group found many techniques in common use throughout the Army test communities. These include:

- o Time series analysis
- o Regression analysis
- o Analysis of variance
- o Classical experimental design
- o Nonparametric procedures
- o Sequential procedures
- o Response surface methodology
- o Multivariate analysis

Three other techniques--the use of interactive computer graphics in statistics, exploratory data analysis, and empirical Bayes--deserve more attention in the test communities. The Study Group considered that the first, interactive computer graphics, might be highly valuable.

As a next step in developing our taxonomy of models, techniques were identified that are under development and might be useful to the Army (items marked with an asterisk are considered to have the most potential):

- o Robust techniques*
- o Accelerated testing*
- o Software reliability for statistical computer graphics*
- o Autoregressive Integrated Moving Average (ARIMA) models:
  - Multivariate
  - Intervention analysis
- o Analysis of variance of time series models
- o Pattern recognition
- o Computational statistics

Finally, the Group identified techniques requiring further basic research for future application:

- o Evaluation of software reliability for systems
- o Multivariate quantile response problem*
- o ARIMA models: Estimation of order
- o Multiple comparison procedures with general application
- o Use of prior information to predict the effect of a proposed modification on reliability
- o Use of nondestructive test results to draw inferences concerning performance

Question 3. To what extent are state-of-the-art statistical techniques currently being applied? What might be done to expand the use of such techniques in testing?

Finding. As with the Study Group assessment of statistical expertise available to the Army, it was found that the Army test communities are generally adequate in applying techniques and, in some areas, are leaders in the field. For example, the Group examined some tests and research projects that it considered to be examples of outstanding successes in terms of statistical methodology. These included the following:

- o Nonparametric Estimation Using Accelerated Test Data (ARO)
- o Sequential Sampling Plans:
  - TOW/Dragon Gunner Training Study (ARO/USA Training & Doctrine Command (TRADOC))
  - Plate Acceptance Firings for K.E. Penetrators Ballistic Research Laboratory (BRL)
  - Plan to Replace Chain Sampling Plan for Rocket Acceptance Tests (AMSAA)
- o Multidimensional Contingency Table Analysis of NATO Small Arms Trials Data (USA Operational Test & Evaluation Agency (OTEA)/ARO)
- o Stochastic Design for Detonation Propagation Problem (BRL)
- o Statistical Test Design Plan for SLUFAE (USA Test & Evaluation Command (TECOM))

Testing methodology is not of uniform high quality, however. Although an exhaustive survey of the areas, could not be made, the Study Group was concerned by test planning in product acceptance and surveillance testing. The resources expended in these testing areas are quite high, and most of the plans are designed at organizations (e.g., PADs) at which minimal statistical expertise is available. Based on a limited examination of those areas, the Group believes that a much more detailed review is needed.

There are many constraints in real-world testing that limit the implementation of techniques, often resulting in the use of techniques that are not as sophisticated as otherwise possible (i.e., are not up to the-state-of-the-art). These constraints include limitations of time, money, material, people, and measurement techniques.

Another area of concern to the Study Group is an apparent lack of early coordination and interchange of information and needs among the Project Managers, the test designers, and the contractor, with a resulting impact on the quality of development and operational testing. The group learned of several incidents in which late changes in the schedules and analysis requirements have severely affected the quality of both the testing and analysis. Some of these incidents might have been avoided with better communication. Finally, in the area of communication, the Group was told of several conflicts in reported results that may have been due to the use of different data sets, or to the same data set being used in an attempt to answer different questions, but which were interpreted as conflicts in analysis. More care in explaining statistical test results to decision-makers is essential.

The final area of concern, in terms of the quality of testing, is the lack of a well-documented audit trail throughout the development and testing processes. First, quantitative parameters in requirements documents are stated without supporting rationale. Then, test designs are made and presented without accompanying rationale. Finally, after most equipment is fielded, there is no effective collection of reliability, maintainability, or performance data to help improve the fielded system, assist in the development of future systems requirements, develop better future test plans for similar systems, or to validate and improve predictive models.

IV. CONCLUSIONS. The Army possesses enough sufficiently qualified statisticians to conduct the design and analysis required by the Army testing activities.

As a result of the review of the cases presented by the Army testing agencies, the Study Group believes that the Army agencies are doing a generally adequate—and often very good--job in their statistical activities.

The Study Group is very favorably impressed by the continuing efforts of the Army statistical community to improve and keep current with the state-of-the-art through such vehicles as workshops and courses.

V. RECOMMENDATIONS. The following recommendations are intended to permit the Army to more fully exploit the capabilities described above:

A. The Army has several "Centers of Excellence" in statistical techniques, tests, and analyses involved in testing (e.g., AMSAA, BRL, Combat Development Experimentation Command (CDEC), OTEA, TECOM). However, a portion of surveillance testing, acceptance testing, and DT and OT of minor systems is being conducted by the PADs, the Boards, and the Proving Grounds. This constitutes tremendous testing expenditures. The Study

Group found that the statistical expertise just described is not always available to these latter types of organizations. Therefore, it is recommended that the Army task its Centers of Excellence to immediately structure a program to help upgrade the quality of these statistical activities by making periodic visits and reviews, and by encouraging consultations.

B. Test designers and analysts from the OT and DT communities and the contractor must be required to meet at the earliest possible date and periodically thereafter to coordinate their objectives and data needs. The Project Managers must be responsible for such coordination.

C. The quantitative portion of the requirement documents must be accompanied by a rationale with supporting justification. That rationale must be made available to the appropriate test communities.

D. The test designs and plans for analysis developed by the test organizations must also be accompanied by supporting rationale. Among other things, this rationale will help reduce the confusion in interpreting test results and will indicate the risks implied by the test plans.

E. Schedule changes (time as well as content) in development programs that affect test designs and analyses must immediately be made known to all concerned. This recommendation is intended to emphasize the importance the Army places on the testing component of the development cycle and the need to provide sufficient time for analysis.

F. Post-Initial Operational Capability (IOC) field data should be collected for the purposes of:

1. Making product improvements more effective.
2. Making future requirements more meaningful.
3. Validating and improving predictive models.
4. Developing more efficient future test plans.

Obviously, all the Centers of Excellence should be involved in the design of such a system.

APPENDIX A
TERMS OF REFERENCE

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, D.C. 20310

REPLY TO
ATTENTION OF

16 MAY 1980

Dr. J. Ernest Wilkins, Jr.
Associate General Manager
EG&G Idaho, Incorporated
Post Office Box 1625
Idaho Falls, Idaho 83401

Dear Dr. Wilkins,

Request you select four or five Army Science Board members to participate in a Summer Study to examine statistical concepts underlying Army testing practices, with a view toward extracting high confidence based on generally fewer tests. If you are free to participate, it would appear appropriate to apply your expertise in this work. It would be appropriate to review current approaches with representatives of TRADOC, DARCOM, and OTEA, some of whom might be asked to participate with the Study Group. Current state of the art statistical techniques and improved designs for testing should be considered in addressing these Terms of Reference (TOR):

1. What areas of Army testing lead to stated, quantified results (e.g., reliability, safety, maintainability, production acceptability/yield) with specified confidence levels?

2. What experimental models are currently applied to such confidence level related testing? How could more modern test designs and models maintain the same confidence levels while reducing test expenses?

3. To what extent are state of the art statistical techniques currently being applied? What might be done to expand the use of such techniques in testing?

Preliminary briefings should be scheduled over the next few weeks. We have arranged for this group to meet 7 through 11 July 1980 at the Armed Forces Staff College, Norfolk, Virginia for discussion and final report writing. A brief-out would be scheduled prior to lunch 11 July to synopsize the findings.

I am confident that this effort can provide the Army with quidelines allowing continued high confidence in its equipment with more economy in testing.

Sincerely,

(Signed) Percy A. Pierre

Percy A. Pierre
Assistant Secretary of the Army
(Research, Development and Acquisition)

APPENDIX B
STUDY PARTICIPANTS

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Mr. Abraham Golub

Ms. Karen D. Pettigrew

Dr. William L. Root

Dr. Victor K. T. Tang

Contributing Army Members

Dr. Marion Bryson, TRADOC

Dr. Jagdish Chandra, ARO

Dr. Larry Crow, AMSAA

Dr. Robert Launer, ARO

Mr. Fred McCoy, OTEA

Dr. David Miller, OTEA

Dr. Dick Moore, BRL

Dr. Ted Trybul, TECOM

Mr. John Tyler, ODCSRDA

Mr. Lang Withers, OTEA

Dr. Stephen Wolff, BRL

Dr. Joseph H. Yang,
Executive Director, ASB

COL Roger W. Mickelson,
Executive Secretary, ASB

LTC Dennis O'Connor, ODCSRDA,
Military Assistant

APPENDIX C
ACRONYM DEFINITIONS

ALMC	Army Logistics Management Center
AMETA	Army Management Engineering Training Activity
AMSAA	Army Materiel Systems Analysis Agency
ARIMA	Auto Regressive Integrated Moving Average
ARO	Army Research Office
ASB	Army Science Board
ASA(RDA)	sistant Secretary of the Army (Research, Development & Acquisition)
BRL	Ballistic Research Laboratory
CDEC	Combat Development Experimentation Command
DT	Development Test
DT&E	Development Test and Evaluation
IOC	Initial Operational Capability
OT	Operational Test
OT&E	Operational Test and Evaluation
OTEA	Operational Test and Evaluation Agency
PAD	Product Assurance Directorate
R&D	Research and Development
TECOM	Test and Evaluation Command
TOR	Terms of Reference
TRADOC	Training and Doctrine Command

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